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The Effects of Fatigue on Biomechanics of Soccer Shooting

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THE EFFECTS OF FATIGUE ON BIOMECHANICS OF SOCCER SHOOTING

A Thesis Presented

By

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ABSTRACT

Title of Thesis: **THE EFFECTS OF FATIGUE ON BIOMECHANICS OF SOCCER SHOOTING**

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Soccer is reputedly the most popular sport in the world with over 40 million registered players. Because soccer is a sport that is played mainly with the use of lower extremity, it is important to know about the fatigue in lower extremity and how muscle fatigue affects to the performance such as kicking, shooting, and passing. The purpose of this study was to examine the effects of fatigue on the kinematic changes in the lower extremity in soccer shooting. Six competitive collegiate male soccer players (n = 6) participated in this study (height: 1.76 ± 0.06 m; weight: 71.38 ± 9.55 kg; age: 21.50 ± 3.15 years old). Five joint reflective markers were placed on the right side of the participant at the (sagittal plane) greater tubercle of humerus, greater trochanter of femur, lateral epicondyle of the femur, medial malleolus, and base of fifth metatarsal. Each participant completed a fatigue protocol that was taken 90 seconds. Participants were asked to complete five shooting trials prior to the fatigue protocol as the baseline (Time 0) and then five more times after completion of each fatigue protocol (Time 1-5). A standard two-dimensional kinematic analysis was conducted with a high-speed video camera to capture the kinematic movement in the sagittal view at 120 Hz during soccer shooting performance. The statistical significance of the differences between pre and post fatigue protocol data was conducted with a one-way repeated measure ANOVA ($\alpha = 0.05$) and followed by *t*-test with Bonferroni adjustment. Analysis of variance with repeated measures indicated significant decreases ($p < 0.05$) in ball velocity after time 2 ($p = 0.38$), time 4 ($p = 0.40$), and time 5 ($p = 0.30$). No significant difference was showed on the angular displacement, velocity, and acceleration of the lower extremities. The results of this study showed that fatigue caused ball's shooting velocity to be significantly lower. Therefore, this study provides a crucial understanding about how exercise-induced fatigue can affect soccer shooting performance. Practitioners can utilize this information and prescribe proper strength and conditioning program to players to maximize their performance. Additionally, soccer coaches can use this information to determine the appropriate timing for player substitution during a game.

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Soccer is reputedly the most popular sport in the world. There are 11 players in each team, and the objective is to score goals by forcing the ball into the opponent's goal line. In the rules of soccer, the major restriction is that the player cannot use their arms and hands except for during throw-in situation. That is why most of strategies and skills have been accomplished by using a player's lower extremity. That being said shooting a ball as fast as possible towards the goal is very important to win a soccer game.

However, all soccer players experience fatigue during a game, and fatigue may cause a decrease in their soccer performance especially in kicking ball velocity. In soccer proficiency, fatigue is considered as an important factor and player's shooting ability is seen as one of the most important determinants of soccer performance. These decrements of performance could be induced by muscle fatigue, psychological factors, and kinematical change in athletes' motion, deficient of nutrition or a problem of cardiopulmonary function.

Research studies have been conducted on the effects of fatigue on the action of soccer kicking such as body posture, footwear, muscle strength and power output and fatigue.[1-3] Additionally, research studies found that after fatigue an increased electro-mechanical delay and knee joint laxity occurs together with a significant decline of maximum isokinetic moment of force on both knee extensors and flexors.[4-5] It is evident that fatigue can affect muscle force. However, the question of how fatigue affects the mechanics of soccer shooting performance remained unanswered. The athletic trainer is a part of the health care team and provide injury and illness prevention, wellness promotion and education, emergent care, examination and clinical diagnosis, therapeutic intervention, and rehabilitation of injuries and medical condition.[6] As an athletic trainer, it is very important to manage changes in an athlete's physical condition as they experience fatigued during the game or practice, and also trainer should understand what factors may hinder their performance and provide appropriate exercises to strengthen their deficiencies. Therefore, the purpose of this study was to examine the effects of fatigue on the kinematical changes in the lower extremity in soccer shooting skill. Specifically, the kinematic variables of joint angle, velocity, and acceleration of the hip, knee and ankle joints for both before and after fatigue protocol were examined. Through this research study, athletic trainers and coaches can understand how exercise-induced muscle fatigue would affect soccer performance and prescribe proper strength and conditioning program to players to maximize their performance and minimize lower extremity injury.

LITERATURE REVIEW

Game of Soccer

Soccer is reputedly the most popular sport in the world with over 40 million registered players and many more hundreds of mullion of people participated in the game.[7] The game is played on a field maximally 68 meters wide and 105 meters long on the surface of grass or gravel. Lately, artificial turf surfaces have been introduced. A regulation game consists of two 45-minute halves with a 15 minutes break at half-time. Soccer is a very old sport and is one of the most popular sports in the world with approximately 150 countries associated with Federation International de Football Association (FIFA), which was founded in 1904. The estimated number of licensed players in 1984 was about 60 million, but it has been estimated that there are another 60 million unlicensed soccer players, mainly youth and recreational players, who participate in local soccer leagues.[8]

There are 11 players in each team and the objective of the game is to score as many points as possible by kicking/shooting the ball into the opponent's goal line. In the rules of soccer, a major restriction is that players cannot use their arms and hands except for during throw-in situation. That is why most of game strategies and skills have been accomplished by using player's lower extremity.

Soccer is characterized as a high intensity and intermittent exercise. Players cover approximately 10,000 m of ground per game, of which 8% to 18% is at the highest individual speed. In higher levels of competition there are a greater number of tackles and headings plus a greater percentage of the game is performed at the maximum speed. The average aerobic energy during a national level game is approximately 80% of the individual's maximum capacity, and the blood lactate concentration during a game averages 7 to 8 mmol/L.

Fatigue

Muscle fatigue can be defined as a loss of force-generating capacity or a failure to maintain force output after continuous muscle contractions.[9] Although several factors may contribute to fatigue, fatigue can generally be classified either as peripheral or central model.[10] In peripheral model, the ability of body to synthesize adenosine triphosphate (ATP) is a physiological factor. This process is involved with oxygen consumption and utilization, metabolic acidosis (e.g. accumulation of hydrogen ions), glycogen depletion in the working muscles.[11] Additionally, action potential generation at the neuromuscular junction and the sarcolemma, amount of calcium release, declined function of contractile element (e.g. excitation-contraction coupling) are considered as neuromuscular factors.[12] On the other hand, a reduction of motor drive signal from the cerebral cortex along with alterations in neurotransmission rate and motor unit recruitment within the brain and spinal cord is considered as the primary factors in the central fatigue model.[13]

Muscle fatigue by continuous voluntary contractions resulted in a reduction of force output and activation from the fatigued muscle.[14-15] For example, a 25.4% decrease in knee extensors force output after continuous Maximal Voluntary Isometric Contraction (MVIC) until 25% drop of their own peak torque and a decrease 40% in knee extensors force output after 50 MVIC at 90°/s against an isokinetic dynamometer.[16, 17] Hart reported that a decrease 10.5% in quadriceps activation after three sets of repeated 10 second periods of gravity-resisted isometric contractions followed by a 10 second rest. The causes of a reduction of force output and activation from the fatigued muscle may arise from peripheral factors. One study demonstrated a significant effect of the work on breathing during strenuous exercise on performance time to exhaustion in healthy and physically trained individuals.[18] They stated that increasing work on breathing curtailed performance and respiratory muscle unloading during exercise was also associated with reduced VO_2 hyperventilation and reduced perceptions of respiratory and limb discomfort.

Biomechanics of Soccer Shooting

In the mechanics of soccer shooting motion, the leg moves in all three planes, so ideally the kinematics of the kicking skill shall be completely defined and conducted using three-dimensional analysis. Nevertheless, there were limited research studies conducted with three-dimensional analysis in the literature. Most kinematic data are the result of two-dimensional sagittal plane studies that have invariably used cine-film at ample rates between 64 and 200 Hz because the movement of the soccer kicking motion predominantly occurs in two dimensions. Also, the high speed of the action implies some of the data derived from using low sample rates may not be reliable.

In terms of kicking success in shooting, one of the measures is ball velocity. Previous studies have reported the mean maximum ball velocity to be in the range 20-30m/s for experienced male adult players.[19-24] Isokawa used a restricted approach and reported mean maximum ball velocity was between 18-20 m/s.[25] Other studies on children have been reported that the mean maximum ball velocity for children aged 8-14 years was 12.0-15.5 m/s and aged 10-17 years was 15.0-22.0 m/s.[26-27] These studies indicate that both skill level and maturity may affect ball velocity.[19] Also, these studies found that the maximum velocity of the foot segment when the foot hits the ball is typically slower than those quoted for ball speed, ranging from 18 to 28 m/s. Authors further evaluated a ball to foot speed ratio and found that this variable may be used to determine a soccer player's kicking skill.[19] For instep kick, ball to foot speed ratios have been studied to range from 1.06 to 1.29 but can exceed 1.5 for kicks using different parts of the foot such as the side-foot kick in soccer or the place kick in rugby.[28] As the foot is in a plantar-flexed position before the impact with the ball, the toes of the foot reach a greater speed than the center of mass of the foot, which results in a greater speed than the ankle joint. Harms further examined both ankle and toe speeds for short approach kicking. Using the toes as an indicator of foot speed, a value of 1.11 was obtained for the ball-to-foot speed ratio and a value of 1.65 was obtained with the use of ankle as an indicator.[29] For the ankle joint, correlations between ball and foot speed are generally high, suggesting that foot speed is a significant factor in the mechanics of foot speed impact between foot and ball. Asami reported that a significant correlation of 0.74 for professional soccer players performing a maximal instep kick, and Isokawa found a significant correlation of 0.52 for maximal instep kicks but with the approach angle varying between 0° to 30°.[19] Wickstrom explained the movement of a proficient kicking skill and suggested that there are four stages in a soccer kicking skill: (1) the withdrawal of the thigh and shank during the backswing, (2) the rotation of the thigh and shank forwards, which occurs as a result of hip flexion; (3) when the thigh angular velocity reduces, there is a corresponding increase in shank angular velocity up to impact with the ball; and (4) the follow through.[30] The thigh angular velocities at impact of -2.8 to 5.4 rad/s have been reported in adult players.[28, 31] For children, one study reported that the mean thigh angular velocities of up to 5.9 rad/s.[32]

In previous literature there were limited research studies that used three-dimensional analysis.[33] Kellis studied kicking motions by conducting a three-dimensional analysis with six cameras.[34] Data were collected using 3D Vicon motion analysis system operated at 200 Hz. The cameras were calibrated to a volume of 2.0 m^3 and the calibration were all below 3mm. From the data analysis, the main effect for type of kick was not significant. No statistically significant interaction effect (type of kick x phase) was observed for hip or knee angular velocity ($p > 0.05$). The results indicated a non-significant interaction (type x phase) for ankle angular velocity during the pre-support phase. In contrast, there was a significant interaction effect during the support phase. The post hoc analysis indicated that the instep kick showed significantly higher ankle angular velocity from 40% to 80% of the support phase compared with the outstep kick.

Muscle Fatigue in Soccer

Human exercise-induced muscle is defined as a loss of force-generating capacity after continuous muscle contractions.[35] Although the exact mechanisms are not clear, the fatigue could be divided into central and peripheral fatigue in our body.[36] The central fatigue hypothesis suggested that an exercise-induced increase in extracellular serotonin concentrations in several brain regions contributed to the development of fatigue during prolonged exercise. Serotonin has been connected to fatigue because of its well-known effects on sleep, lethargy, drowsiness and loss of motivation. Noakes has attempted to manipulate central serotonergic activity during exercise, but this work has yet to provide strong evidence for a significant role of serotonin in the fatigue process.[37] However, it is important to note that brain function is not determined by a single neurotransmitter system, and the interaction between brain serotonin and dopamine during prolonged exercise has also been explored as having a regulative role in the development of fatigue. This revised central fatigue hypothesis suggests that an increase in central ratio of serotonin to dopamine is associated with feelings of tiredness and lethargy, accelerating the onset of fatigue, whereas a low ratio favors improved performance through the maintenance of motivation and arousal. The peripheral fatigue is occurred with the processes in motor neuron, neuromuscular junction, sarcolemma membrane, excitation-contraction coupling, accumulation of metabolites, or depletion of fuel.[38]

Mohr described that a time-motion analyses and performance measures during match-play. Fatigue or reduced performance seems to occur at three different stages in the game: (1) after short-term intense periods in both halves; (2) in the initial phase of the second half; and (3) towards the end of the game.[39] The exercise intensity of soccer players declines in periods during a game, most likely due to fatigue. These critical parts of the game may be immediately after short-term intense periods (temporary fatigue), in the initial phase of the second half, and towards the end of the game. The physiological mechanisms responsible for fatigue appear to change during different periods of a match. Temporary fatigue may be related to disturbed muscle ion homeostasis. Impaired exercise ability in the first few minutes after half-time could be explained by a markedly lowered muscle temperature at the start of second half. The decrement in the last stage of a game may be caused by depletion of muscle glycogen in individual fibers, under thermal stress conditions, dehydration and the concomitant hyperthermia.

Research studies were conducted on the effects of fatigue in soccer kicking such as body posture, technical approach, footwear, muscle strength and power output and fatigue.[4, 31, 39-41] Even though, in soccer and soccer proficiency, fatigue is considered as an important factor and despite the fact that player kicking ability is seen as one of the most important determinants of soccer performance, few studies have examined the effects of fatigue on ball velocity and the mechanics soccer kicking performance.

Summary

Previous research studies have been conducted on changes of soccer shooting velocity or accuracy after half time, game, or fatigue session. Some studies also have examined the effects of fatigue on biomechanical changes in soccer shooting and landing.[4, 31, 39-41] However, research studies that evaluated both ball velocity and biomechanical changes in the lower extremity body joints have yet been examined. Most of research studies have shown that the abilities of shooting velocity or accuracy decrease based on muscle function. However, understanding how muscle fatigue may change soccer shooting mechanics is still unclear. Due to the lack of empirical evidence, it is critical to examine the changes in kicking ball velocity as a result of changes in mechanical kicking movement from fatigue. From the results of this study, coaches and trainers can understand how exercise-induced muscle fatigue affects soccer performance and prescribe proper strength and conditioning program to players to maximize performance and minimize lower extremity injury.

METHODS

Participants

Six competitive collegiate male soccer players (n = 6) between the ages of 18-26 years old participated in this study (Table 1). Participants were excluded if they had any orthopedic injuries for the past six months or a history of surgery to their back or lower extremity. This study was approved by the institutional ethics review board before conduction the experiment. All written consent form was obtained from the participants prior to testing.

Table 1. Demographic

	Height (m)	Weight (kg)	Age (years)
Mean (SD)	1.76 (0.06)	71.38 (9.55)	21.5 (3.15)

Experimental Setup

Five joint reflective markers were placed on the body (sagittal plane) including participant's greater tubercle of humerus, greater trochanter of femur, lateral epicondyle of the femur, lateral malleolus, and fifth metatarsal. Participants completed a soccer course that lasted 90 seconds to induce fatigue. Serresse investigated the contribution of three body energy systems during maximal work of 10, 30, and 90 seconds.[42] Based on the study, participants used their energy production system as oxidative pathway during 90 seconds protocol. Ferraz showed that lactate concentration increased significantly after completion of the 90 seconds fatigue circuit.[2] Thus, the fatigue protocol soccer course in this study mimicked a real game situation, and it consisted of running, pivoting, cutting, jumping and shooting. Data collection was conducted in one session and took approximately 30 minutes in duration for each player. A Casio high speed video camera (Model: Ex-FH25) was used to capture the kinematic movement in the sagittal view during the pre and post fatigue conditions. In addition, a 650W artificial lighting was used to assist in identifying the joint reflective markers.

Procedures

All participants were asked to wear a pair of black shorts and a short-sleeved t-shirt. Participants were asked to perform 10 minutes warm up as they would prior to the game. For the baseline data collection, participants kicked a soccer ball (size: 5; circumference: 0.69 m; weight: 0.45 kg) that is placed 11m (distance of penalty kick) away from a wall for five trials. After the baseline (Time 0), participants performed the fatigue protocol which includes running, pivoting, cutting, jumping and shooting for a total of five times. Participants were asked to complete five trials of shooting and heading after each completion fatigue protocol (Time 1 to 5).

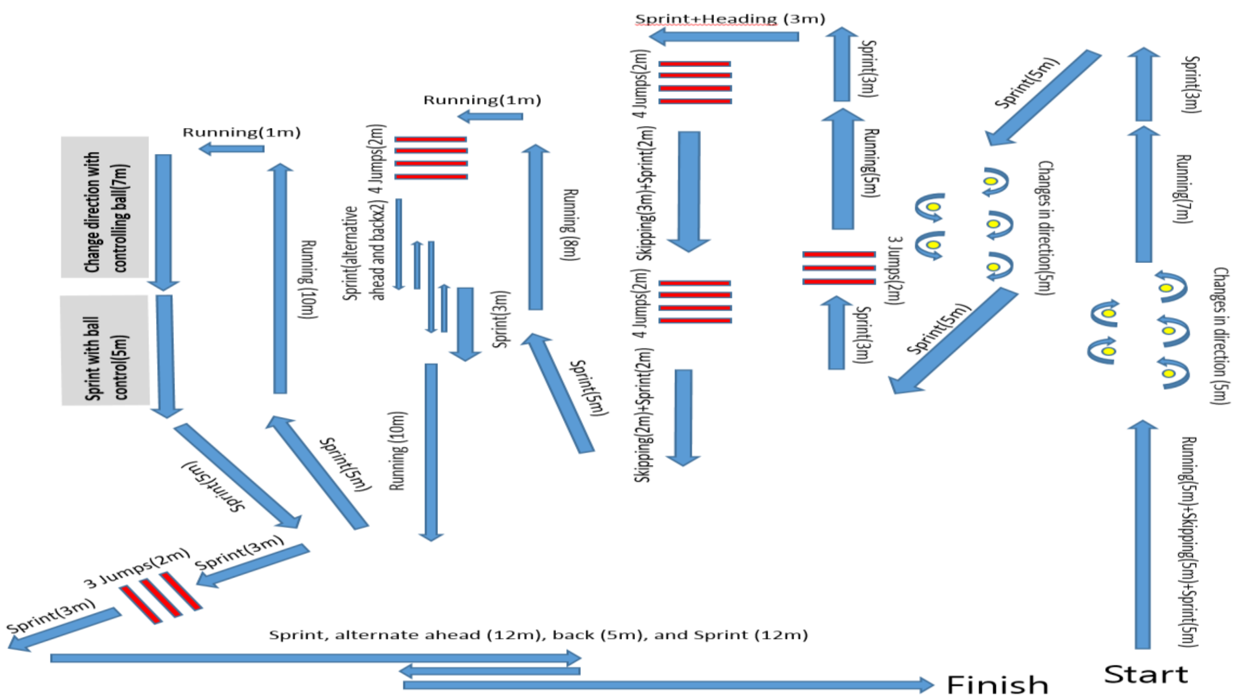

Figure 1. Fatigue protocol

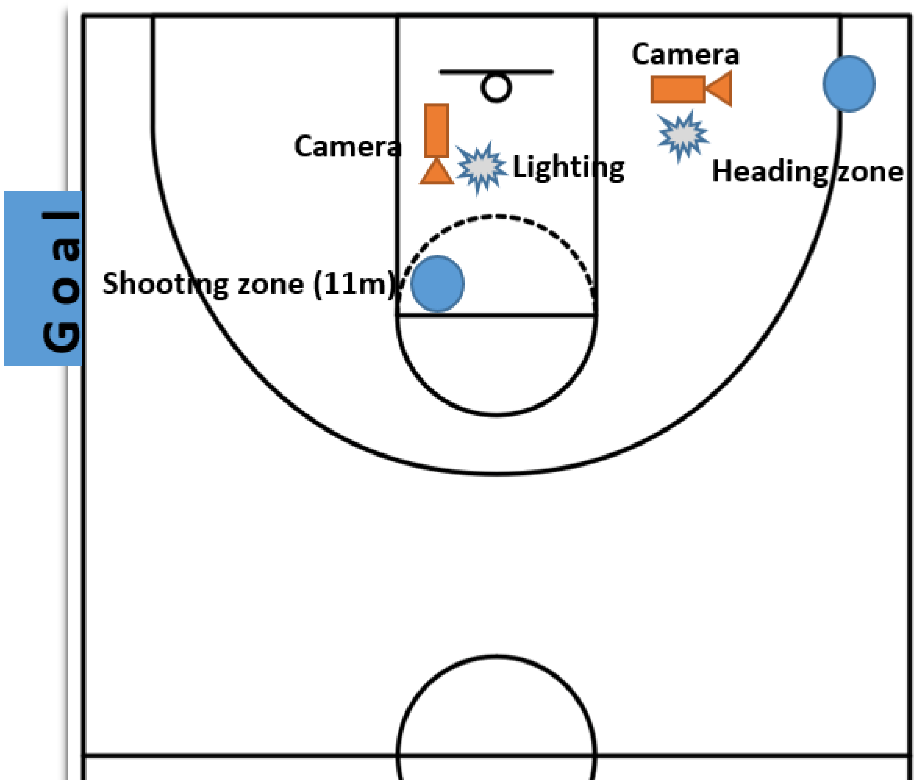

Figure 2. Shooting zone

Data Processing

Since each participant kicked the ball for five trials from Time 0 (Baseline) to Time 5, a total of 180 trials (6 participants x 5 kicks x 6 times) were collected in this study. All video trials were transferred onto a computer in the Biomechanics Lab. A standard two-dimensional kinematic analysis was conducted with Ariel Performance Analysis System (APAS) ™ software, and a digital filter function (cut-off frequency: x = 8 Hz; y = 8 Hz) was applied to reduce the noise of the data. Three trials out of five were selected based on the ball velocity. The average of the three trials in each condition for the ball velocity and acceleration and hip, knee, ankle joint angles, velocities and accelerations were calculated and used for statistical analysis.

Statistical Analysis

A one-way repeated measure analysis of variance (ANOVA) was conducted at $\alpha = 0.05$ and followed up by *t*-test with Bonferroni adjustment if a significant difference was found. The statistical analysis was conducted with SPSS (v. 24) software.

RESULTS

A one-way repeated measure ANOVA was conducted at $\alpha = 0.05$ for the ball velocity between six times. Figure 1 shows that the differences of ball velocity between the times. Compared to the time 0 (baseline), there was a 17.5% reduction at time 2 ($p = 0.38$), 19.6% reduction at time 4 ($p = 0.40$), and a 17.8% at time 5 ($p = 0.30$).

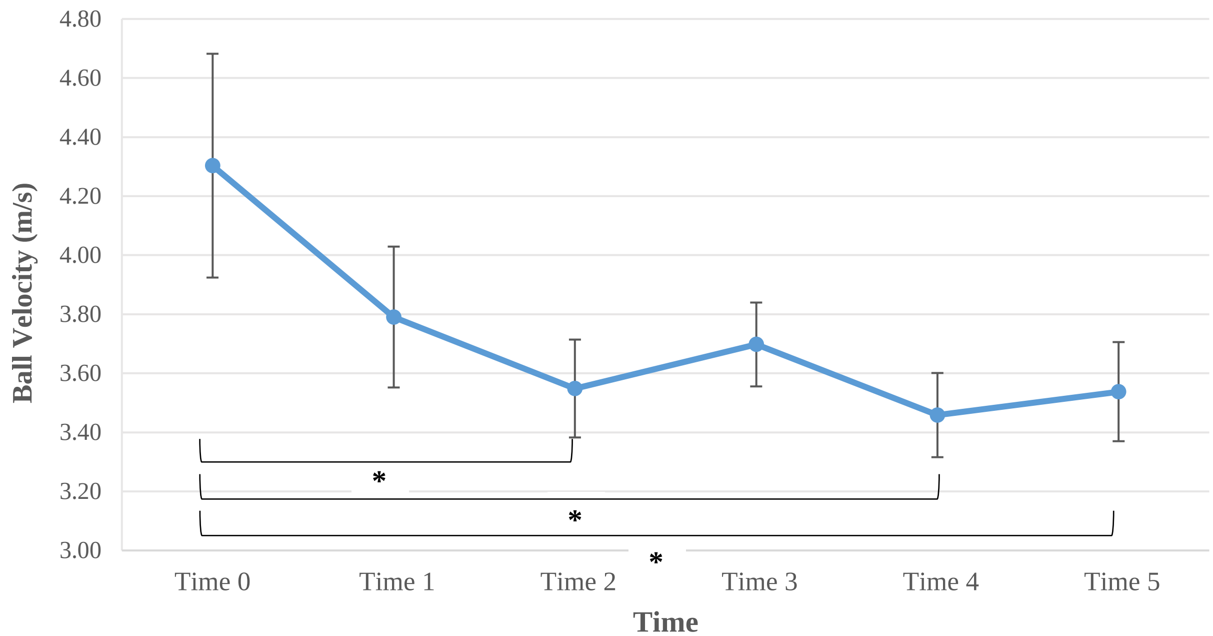

Figure 3. Changes in ball velocity of shooting at a moment of ball contact

A one-way repeated measure ANOVA was conducted at $\alpha = 0.05$ for the angular displacements of hip, knee, and ankle joints (Table 2). There was no significant difference between the times by using the Huynh-Feldt correction in the repeated measure ANOVA design.

Table 2. Angular displacement of lower extremities at the moment of ball contact

Mean ° (SD)	Time 0	Time 1	Time 2	Time 3	Time 4	Time 5
Hip	166.3 (3.7)	169.1 (2.7)	165.6 (3.9)	167.0 (3.5)	167.5 (3.1)	166.3 (3.7)
Knee	146.4 (4.4)	135.5 (4.9)	135.7 (6.3)	138.8 (5.9)	141.1 (5.5)	135.8 (6.7)
Ankle	142.9 (2.7)	136.9 (2.3)	137.9 (2.0)	138.7 (2.3)	140.5 (2.0)	141.7 (1.5)

A one-way repeated measure ANOVA was conducted at $\alpha = 0.05$ for the angular velocity of hip, knee, and ankle joints (Table 3). There was no significant difference between the times by using the Huynh-Feldt correction in the repeated measure ANOVA design.

Table 3. Angular velocity of lower extremities at the moment of ball contact

Mean °/s (SD)	Time 0	Time 1	Time 2	Time 3	Time 4	Time 5
Hip	-30.9 (50.8)	-29.1 (37.6)	-11.7 (80.2)	-60.1 (31.6)	-1.0 (54.4)	-131.7 (66.8)
Knee	718.7 (48.4)	702.4 (77.0)	706.3 (54.1)	764.8 (94.7)	730.7 (64.1)	846.2 (75.8)
Ankle	-15.8 (70.7)	34.1 (95.9)	88.3 (64.3)	134.5 (73.7)	32.2 (81.4)	12.7 (69.9)

A one-way (shooting x 6 times) repeated measure ANOVA was conducted at $\alpha = 0.05$ for the angular acceleration of hip, knee, and ankle joints (Table 4). There was no significant difference between the times by using the Huynh-Feldt correction in the repeated measure ANOVA design.

Table 4. Angular acceleration of lower extremities at the moment of ball contact

Mean °/s^2 (SD)	Time 0	Time 1	Time 2	Time 3	Time 4	Time 5
Hip	793.6 (517.7)	1277.5 (823.2)	2237.4 (1027.1)	2307.4 (597.3)	1796.8 (1280.7)	1796.2 (1558.8)
Knee	-1314.5 (1086.3)	1327.7 (995.8)	429.9 (744.4)	1371.2 (535.4)	1042.7 (942.5)	4424.6 (1894.9)
Ankle	-3032.1 (2824.9)	3081.9 (1423.8)	1119.3 (2423.8)	2964.4 (2348.6)	3460.9 (1433.8)	2015.8 (2879.5)

DISCUSSION

The purpose of this study was to examine the effects of fatigue on the kinematical changes in the lower extremity in soccer shooting skill. Specifically, the kinematic variables of joint angle, velocity, and acceleration of the hip, knee and ankle joints for both before and after fatigue protocol was examined. With these aims, the author induced fatigue of the lower extremities. After pre and post fatigue protocol, as the author has mentioned above, this study noticed that the ball velocities decreased, which was caused by various factors. However, this study did not show any significant difference on kinematic variables: joint angular displacement, velocity and acceleration of the lower body joints.

One main finding from this study was that the average ball velocity decreased after time 2, time 4, and time 5 of fatigue protocol. Compared to the time 0, there was a 17.5% reduction at time 2 ($p = 0.38$), 19.6% reduction at time 4 ($p = 0.40$), and a 17.8% at time 5 ($p = 0.30$). The decrease in ball velocity at the termination of the fatigue protocols is consistent with results found in other studies.[34, 43] Kellis found significant difference of the maximal velocity of the ball between pre and post fatigue value ($p = 0.01$). Russell said that shooting speeds were slower during the second half compared with the first half (12.2 ± 0.3 m/s vs. 16.6 ± 0.3 m/s, $p = 0.012$).[34] Ferraz found that a significant decrease ($p < 0.05$) in the ball velocity after one round of the fatigue circuit. In other words, this study suggests that the fatigue had a negative influence on ball velocity in soccer shooting.[2]

There are some explanations can be used from a broad range of physiological analyses such as: decreased neuromuscular performance; changes in the pattern of muscle strength;

changes in coordination due to physiological causes, changes in the moment of force of the leg before ball contact; and consequent decrease in strength of the muscles involved in kicking.[44-46] According to Greig, they studied the influence of soccer-specific fatigue on peak isokinetic torque production of the knee flexors and extensors and found that peak eccentric knee flexor torques at the end of the game ($T_{300eccentricH00}$ = 127 ± 25 N·m) and at the end of the passive half-time interval ($T_{300eccentricH15}$ = 133 ± 32 N·m) were significantly reduced relative to the first 15 minutes ($T_{300eccentricH00}$ = 167 ± 35 N·m, $p < 0.01$; $T_{300eccH15}$ = 161 ± 35 N·m, $p = 0.02$).[44] In the Rampinini's study, he found that fatigue was found by a reduction of maximal voluntary contraction (MVC) and sprint performance (-11%, $p = 0.001$ and -3%, $p < 0.001$, respectively).[46]

An interesting result that was found in this study was that the ball velocity decreased inconsistently. In this study the ball velocity did not decrease at the time 3 ($p = 0.3$) significantly compared to the time 0 even though this study found a significant difference at the time 2 ($p = 0.3$). Ferraz also expected that ball velocity would reduce progressively down to a given limit.[32] However, his results showed that after the 3rd circuit, ball velocity started to increase again even though heart rate, RPE and lactate concentration continued to increase. Even though the participants were more fatigued considerably when they started and finished each fatigue protocol, as shown by the increased RPE and heart rate in his study, they were able to maintain a similar distance covered and showed an increase in ball velocity after completion of two fatigue protocols.[2] Ferraz explained this result by using the central governor model and the concept of "pacing".[37, 48-49]

The central governor model is explained by Noakes which is about the phenomenon of fatigue. It proposes that physical activity is controlled by a central governor in the brain and that the human body functions as a complex system during exercise. The subconscious brain regulates power output by modulating motor unit recruitment to preserve whole body homeostasis and prevent catastrophic physiology failure. In present study, it is showed at time 3 that the ball velocity re-increased after time 2 showed decreased velocity compared to the time 0.[48]

Although the ball velocity at the time 5 still has a significant difference (17.8% reduction) compared to time 0, the values showed slightly increased velocity compared to time 4 (19.6% reduction). This can be confirmed by Millet's flush model, based on the principles of the governor model, explained the regulation of fatigue in endurance activities specifically adapted to endurance running by citing the role of motivation and what he calls a security reserve. According to the flush model, people have a reserve for muscle recruitment that can be used for the so-called "end spurt" at the highest level of peripheral fatigue. In the present study, participants might have used "end spurt" at the last session of the whole testing.[49]

In terms of the angular displacement, velocity, and acceleration of the lower extremities, this study did not show any significant difference between the times. Even though the ball velocity decreased by the fatigue protocol, the angular displacement and velocity of the lower extremities were not decreased by the fatigue protocol. Therefore, the fatigue protocol from this study did not affect biomechanics of soccer shooting but physiological changes might have occurred which explains the finding of decrease in ball velocity. However, some studies found that changes in the angular displacement and velocity of the lower extremities during soccer shooting as participants experienced fatigue.[1, 34]

Cortes explained the effects of a functional agility short-term fatigue protocol on lower extremity mechanics and found that the knee position post-fatigue had an increase in knee internal rotation (11.4 ± 7.5° vs. 7.9 ± 6.5° $p = 0.01$) and a decrease in knee flexion angle (−36.6 ± 6.2° vs.−40.0 ±6 .3°, $p = 0.003$) than pre-fatigue. Also, the hip position post-fatigue had a decrease in hip flexion angle (35.5 ± 8.7° vs. 43.2 ± 9.5°, $p = 0.002$).[1] Kellis investigated the effects of an intermittent exercise fatigue protocol on biomechanics of soccer kick performance. He found that post-fatigue maximum angular velocity of the shank (129.26 ± 12.99°), the net moments acting on the shank and the resultant joint moments were significantly lower compared with the corresponding pre-exercise values (144.38 ± 12.93 °, $p < 0.01$).[34] However, in this study they also could not find any significant difference between pre and post fatigue protocol on maximal angular velocity of the thigh ($p > 0.01$) and angular displacement patterns. The results of this study were not entirely consistent with those two studies because these studies used different fatigue protocols. Kellis conducted a 90 minutes intermittent exercise protocol, and Cortes provided a different fatigue protocol (side step, step-up, cut to the contra-lateral side of the dominant foot) as interventions.[1, 34]

The findings of this study may help practitioners prescribe better strength and conditioning program. Even though the result shows a slight increase in the ball velocity, overall, the ball velocity in shooting decreases during the entire fatigue protocol. Considering that shooting a ball as fast as possible towards the goal is one of the important factors to win a soccer game, a strength and conditioning program may then prescribe a program for soccer players to focus on strength and endurance of the lower extremity. Also, coaches can keep their team in better condition as they make a substitution to fatigued player

This research has some limitations that should be considered carefully. All sessions were conducted in an indoor facility not outdoor in this study. Considering that soccer is an outdoor sport, this study cannot explain the soccer performance precisely since other conditions (wind, temperature, grass condition, and etc.) might affect the outcome of the study. All participants were male so this study cannot compare with female who has quite different lower extremity joint angles.[50] Additionally, this study assumed that all participants provided their maximum effort during the testing. The examiner was giving a word to make participants do their best, as hard as they can shoot, while they were shooting, but the examiner could not know that if the participants had completed the fatigue protocol with their maximum effort. Finally, this study could not control psychological factor during the experiment. As the participants become fatigued, they might have been stressed to continue the testing procedure so it might have affected the results.

CONCLUSION

Six competitive collegiate soccer players participated in this study, and each participant performed shooting and fatigue protocol. The results of this study showed that fatigue affected ball's shooting velocity to be significantly lower. These changes did not come from biomechanical changes but physiological changes as there was no significant changes in angular displacement, velocity, and acceleration. Although the fatigue protocol of this study could not elicit kinematical changes in lower extremity joints, the changes in peripheral fatigue were enough to reduce the most important soccer skill, shooting. Therefore, this study provides a crucial understanding about the how exercise-induced fatigue affect soccer performance. Also, practitioners can prescribe proper strength and conditioning program to players to maximize their performance. Additionally, soccer coaches may this information to determine the best timing for player substitution to keep players competitive during the game. Future studies are warranted to evaluate how exercise-induced fatigue may affect changes in lower body kinematics in a longer duration of fatigue protocol and with the use of an EMG system to better understand the level of muscle activity during fatigue.

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APPENDIX A. Mean differences with the Time 0 (Baseline) for angular displacement.

	vs. Times	**Mean Differences ° (SD)**	***p***
Hip	vs. Time 1	-2.8 (2.4)	1.00
	vs. Time 2	0.7 (3.5)	1.00
	vs. Time 3	-0.7 (3.4)	1.00
	vs. Time 4	-1.3 (2.7)	1.00
	vs. Time 5	-0.1 (3.4)	1.00
Knee	vs. Time 1	10.8 (3.2)	0.30
	vs. Time 2	10.6 (3.3)	0.33
	vs. Time 3	7.6 (3.5)	1.00
	vs. Time 4	5.2 (2.8)	1.00
	vs. Time 5	10.6 (10.6)	0.35
Ankle	vs. Time 1	5.9 (1.9)	0.44
	vs. Time 2	5.0 (2.9)	1.00
	vs. Time 3	4.2 (1.4)	0.45
	vs. Time 4	2.5 (1.6)	1.00
	vs. Time 5	1.3 (1.3)	1.00

APPENDIX B. Mean differences with the Time 0 (Baseline) for angular velocity.

	vs. Times	Mean Differences °/s (SD)	*p*
Hip	vs. Time 1	-1.7 (48.1)	1.00
	vs. Time 2	-19.1 (97.9)	1.00
	vs. Time 3	29.3 (48.2)	1.00
	vs. Time 4	-29.8 (56.1)	1.00
	vs. Time 5	99.8 (82.9)	1.00
Knee	vs. Time 1	16.3 (106.7)	1.00
	vs. Time 2	12.4 (85.8)	1.00
	vs. Time 3	-46.1 (117.1)	1.00
	vs. Time 4	-11.9 (103.1)	1.00
	vs. Time 5	-127.5 (75.8)	1.00
Ankle	vs. Time 1	-49.8 (127.5)	1.00
	vs. Time 2	-104.0 (104.3)	1.00
	vs. Time 3	-150.3 (88.9)	1.00
	vs. Time 4	-47.9 (115.7)	1.00
	vs. Time 5	-28.5 (130.2)	1.00

APPENDIX C. Mean differences with the Time 0 for angular acceleration.

	vs. Times	Mean Differences °/s^2 (SD)	*p*
Hip	vs. Time 1	-483.9 (1045.7)	1.00
	vs. Time 2	-1443.8 (1259.6)	1.00
	vs. Time 3	-1513.9 (766.3)	1.00
	vs. Time 4	-1003.2 (1410.7)	1.00
	vs. Time 5	-1001.6 (1468.8)	1.00
Knee	vs. Time 1	-2642.1 (1624.7)	1.00
	vs. Time 2	-1744.5 (1628.1)	1.00
	vs. Time 3	-2685.7 (1316.2)	1.00
	vs. Time 4	-2357.2 (1784.1)	1.00
	vs. Time 5	-5739.1 (2041.5)	1.00
Ankle	vs. Time 1	-6113.9 (3007.9)	1.00
	vs. Time 2	-4151.4 (2407.5)	1.00
	vs. Time 3	-5996.4 (2747.5)	1.00
	vs. Time 4	-6493.1 (3174.2)	1.00
	vs. Time 5	-5047.9 (3121.8)	1.00